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ABSTRACT

Building Research studies show that overheating because of excessive solar heat gains can be troublesome in buildings of lightweight construction with large areas of glazing. The work being done at the Building Research Station provides the data for calculation of peak temperatures resulting from solar heat gain. Attention is given to window size and orientation, ventilation, and the effects of sun-controls. Graphs aid in computing peak temperatures as a function of unshaded window size for multi-story blocks of offices. These graphs determine the maximum permissible areas of glass to be used in offices when heat gain by solar radiation is part of the design criteria. (TC)

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Window design criteria to avoid overheating by excessive solar heat gains

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BUILDING RESEARCH STATION

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WINDOW DESIGN CRITERIA TO AVOID OVERHEATING BY EXCESSIVE SOLAR HEAT GAINS

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This paper was presented at the C. I. E. Intersessional Conference on 'Sunlighting in buildings' at Newcastle-upon-Tyne in April 1965.

Overheating because of excessive solar heat gains can be troublesome in buildings of lightweight construction with large areas of glazing. This note describes work at the Building Research Station on the calculation of peak temperatures resulting from solar heat gains. It takes account of relevant factors such as window size and orientation, ventilation and the effect of sun-controls. Charts are presented giving computed peak temperatures as a function of window size for offices with unshaded windows in multi-storey blocks, and it is shown that the calculated temperatures correlate well with survey data on overheating in offices. Maximum permissible areas of glass to avoid overheating could be determined from charts of this type.

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7 WINDOW DESIGN CRITERIA TO AVOID OVERHEATING BY EXCESSIVE SOLAR HEAT GAINS

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7.1 Introduction

Windows which admit sunlight also admit solar heat, and though heat from the sun is welcome in cool buildings, in excess it can make buildings uncomfortably hot in summer. There is thus an upper limit to the size of windows that can be used without causing thermal discomfort in sunny spells. It is interesting to compare the effects on the thermal and visual environment in a building of increasing the size of windows with a southerly aspect. The thermal environment will generally improve up to a point, and then deteriorate as windows are made larger. For example, if the outside air temperature is 15°C (60°F), a building with small windows which admits only enough solar heat to raise the temperature 3°C will be rather cool (18°C or 65°F). Increasing the window size to double the solar heat gain will make the building comfortably warm (21°C or 70°F), but a further increase in window size to redouble the heat gain will make it too hot (27°C or 80°F). By contrast, the daylight illumination under overcast sky conditions will progressively improve, from a basic level of perhaps 5 lumens/ft^2 with the small windows to, say, about 10 lm/ft^2 with the medium and 20 lm/ft^2 with the large windows. The view also improves as the window size is increased, and although glare from sun and sky is increased, and privacy is reduced, these difficulties can be avoided by using blinds which will not in general solve the overheating problem. The avoidance of summer overheating thus imposes a more stringent upper limit to window size than visual considerations.

Recent changes in the style of building illustrated by the examples in figs. 7.1 and 7.2, have led to greater use of glass and lightweight materials, and to a consequent sharp increase in the amount of overheating experienced in Britain. Thus a 1948 survey by Gray and Corlett (1) of prewar offices with window areas averaging 20% of the floor area, showed that although 85% of the occupants wanted sunshine in their offices, only 9% were concerned that they should not to be hot. By contrast, a 1961 survey of postwar offices described by Langdon and Keighley (2) showed that as many as 40% of the occupants were sometimes too hot in summer.

The probable reasons for the increase in overheating complaints can be discerned from the survey data. Window areas were on average 50% larger in the 1961 survey than in the 1948 survey. Moreover 80% of internal partitions in the post war offices were light in weight, whereas most partitions in prewar buildings were heavy. This is an important point because lightweight materials warm up quickly. Another point is that people now often keep their windows closed to exclude traffic noise, which has increased in recent years, so that ventilation heat losses are reduced. In the 1961 survey there were more complaints of overheating in offices near busy traffic routes than in quieter areas.

The survey also showed that, as would be expected, there were more complaints of overheating when windows faced south of the east-west axis, rather than north, and that there were more complaints in offices with large windows than in offices with small windows. The results are set out in table 7.1 Temperatures during sunny spells are also affected by the nature of internal surfaces, size and shape of room, whether glazing is single

Fig. 7.1
Example of prewar office block

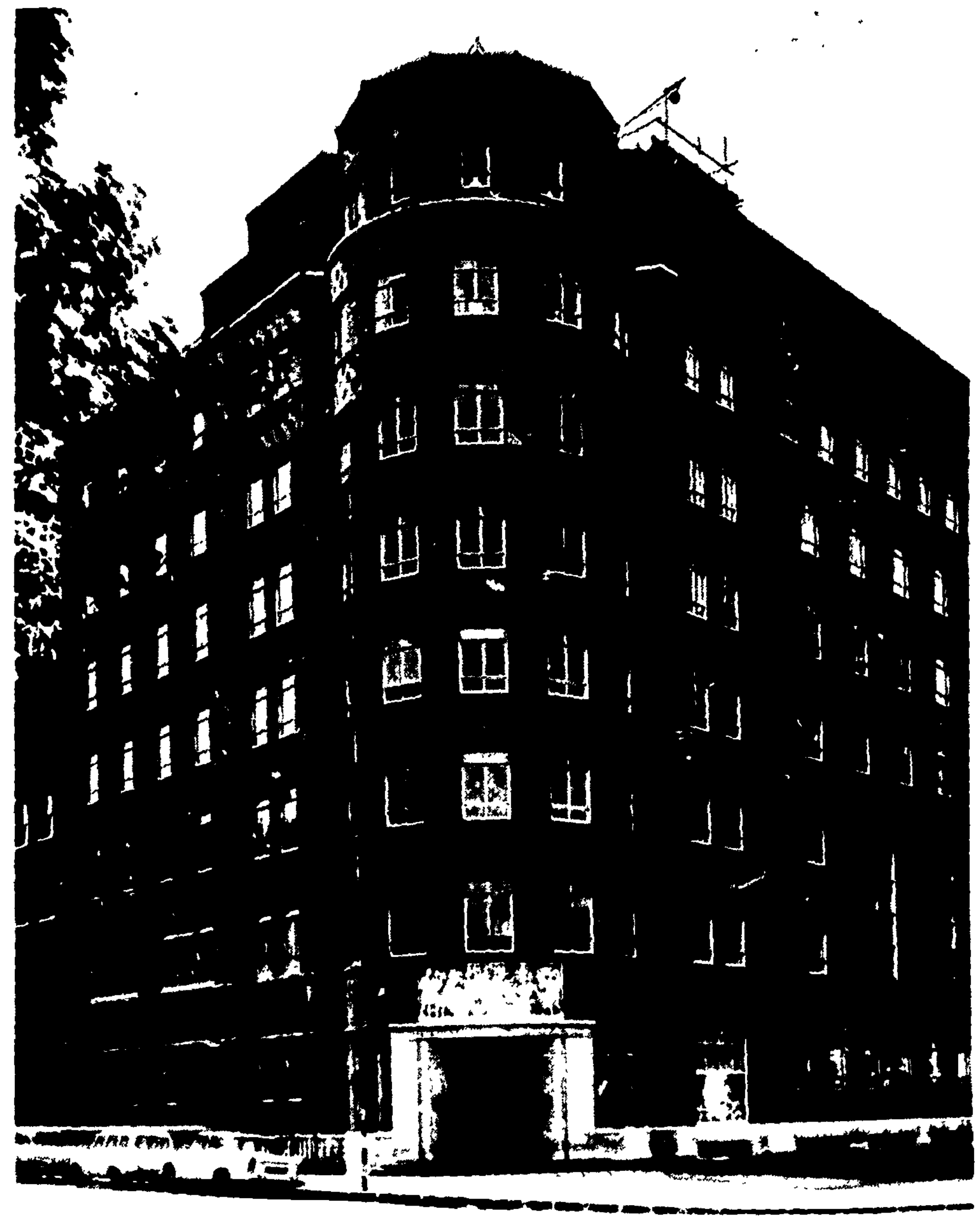
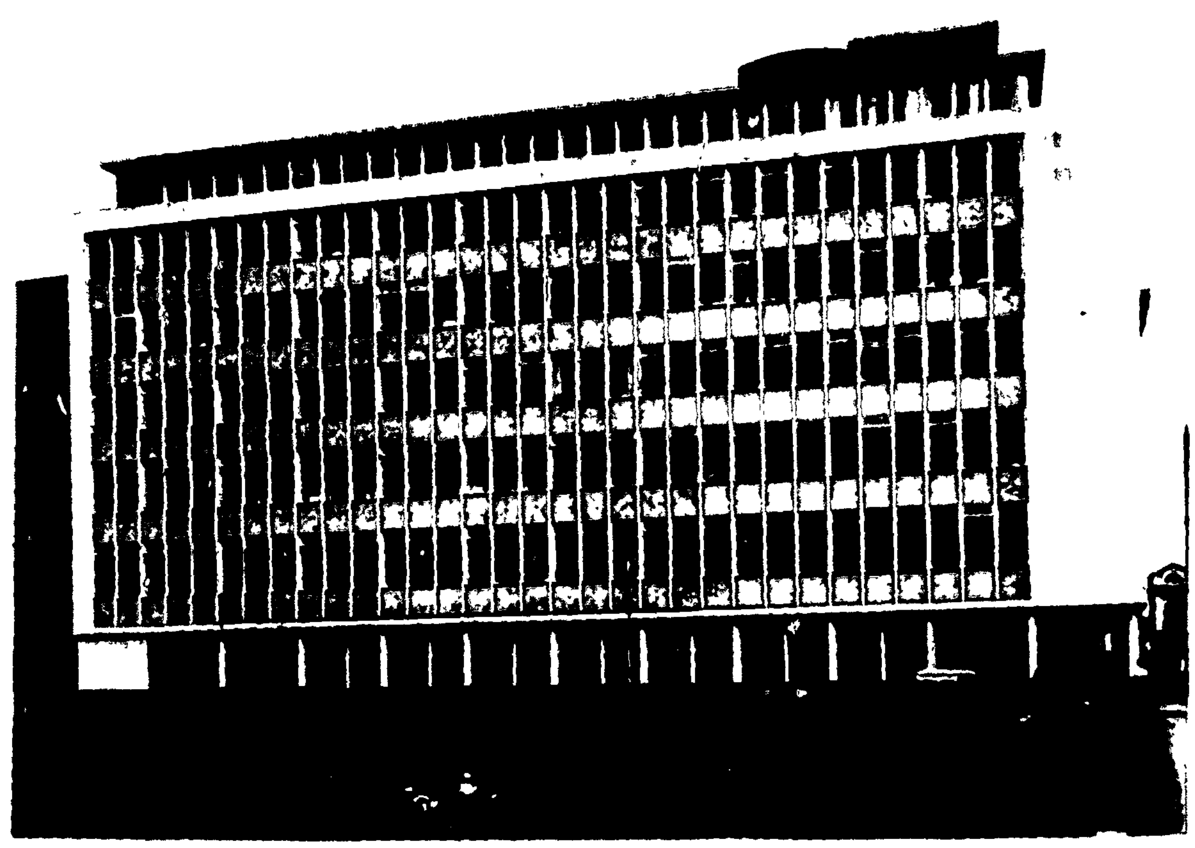


Fig. 7.2
Example of postwar office block



or double, and so on.

Table 7.1
Percentage of occupants either "slightly" or "definitely" uncomfortable because of overheating.

(S and N refer to orientations south and north of the east-west axis).

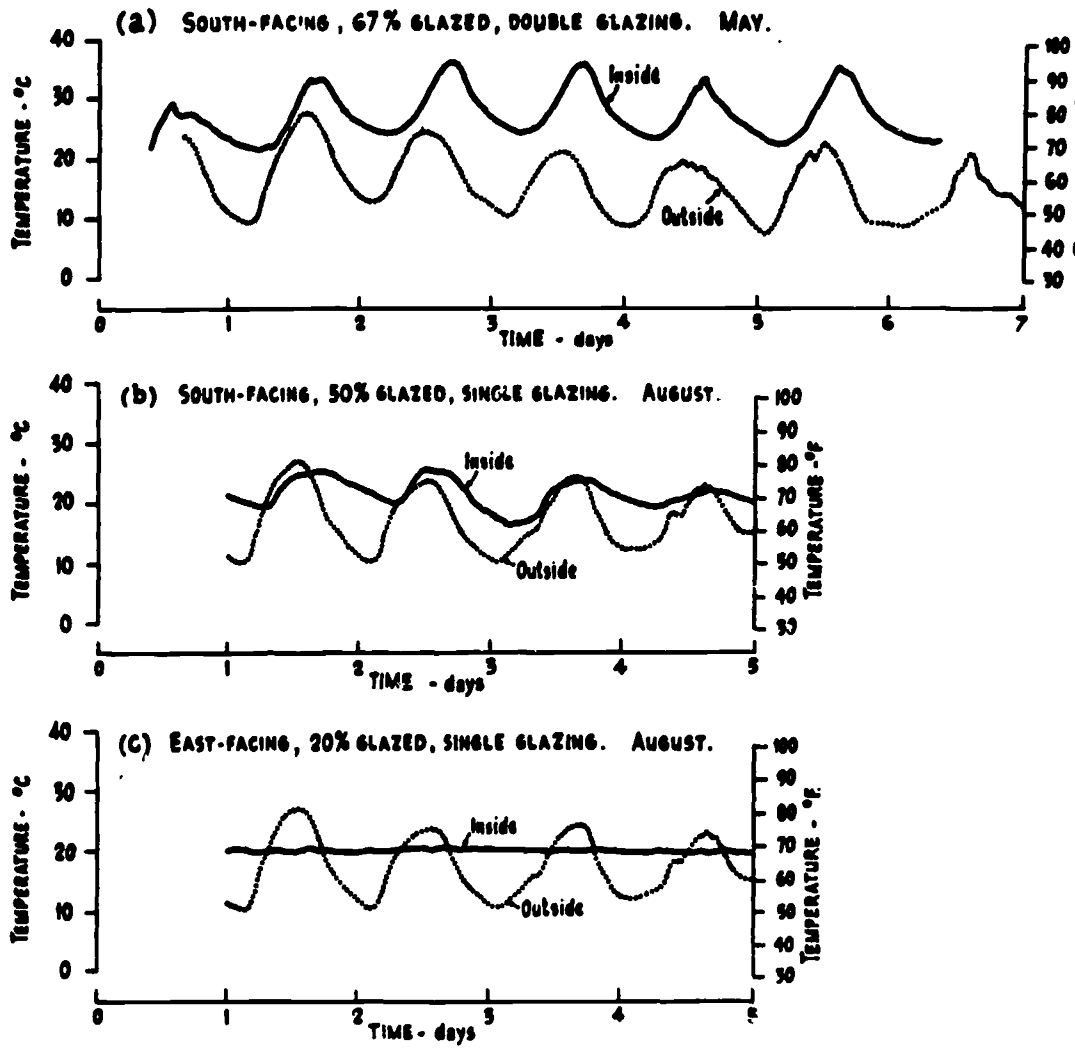
Orientation	Window size as proportion of exposed wall area		
	more than 60%	40 - 60%	25% -40%
S, noisy	66%	49%	48%
S, quiet	47	40	41
N, noisy	37	31	24
N, quiet	23	28	16

7.2 Some examples of the effect of solar radiation on room temperatures

A few practical examples may be of interest in illustrating the effect of solar radiation on the temperatures in different types of room.
Fig. 7.3a shows the temperatures during a "heat-wave" in an office with large double glazed windows, covering 67% of the external wall. It had a lightweight interior - carpeting on wood-block flooring, and lightweight concrete walls.
Temperatures were above 35°C (95°F) during the hottest part of the day, and even the daily-mean internal temperature was above 27° C (80°F) with windows closed. The windows could be opened, but this office was too hot during sunny spells even when it was ventilated fairly freely. Points to note, which are discussed later, are that the mean inside temperature is elevated above the outside mean, and there are large diurnal swings in internal temperature because solar gains are concentrated in a short part of the day.

Fig. 7.3b shows the temperatures in a conference room with single glazed S-facing windows covering 50% of the external wall. It became very warm (up to 26°C or 79°F) on the first two days shown, which were both sunny. On the first day the room was unoccupied and the windows were closed, but on the afternoon of the second day it was occupied and windows were opened. Evidently the ventilation rate was not high enough to keep the internal temperature down to the outside air temperature, and a user complained that "sessions immediately following lunch can be sheer torture as the spoken word is obliterated by sleep! " Heat gains from occupants contributed to the overheating, but solar heat gains also had an important effect.
Much cooler conditions, with a fairly steady temperature of about 20°C or 68°F (fig. 7.3c), were obtained in a records office in the same building during this sunny period. It had E-facing windows, shaded by trees, covering 20% of the external wall, and these were closed during the measuring period. The room had a high thermal capacity, increased by steel storage cabinets.
It is evident, therefore, that rooms differ considerably in their characteristics and that there is a need for criteria to assess in advance whether rooms will get too hot during sunny spells, taking account of all relevant factors such as orientation, ventilation, thermal capacity, shading of windows and so on.

Fig. 7.3
Temperature records during sunny spells



It is necessary to estimate the maximum area of glass which can be used in given circumstances without exceeding a given internal temperature, and how this is affected by using blinds, shades or other types of sun control.
Alternatively if cooling plant is to be installed it is necessary to assess the cooling load and how this can be reduced by using sun-controls or altering the window size. In general terms, therefore, designers need a method of assessing the consequences of using different areas of glass, whether in terms of thermal discomfort or cost of sun-controls or air-conditioning plant.

7.3 The determination of the consequences of glazed areas and sun controls

We have been looking at this question at the Building Research Station and our approach is set out in a paper by Loudon and Danter (3). There are three separate problems: (i) to assess from meteorological data the radiation intensities and air temperatures on warm sunny days, (ii) to derive data on the transmission and absorption of radiation by glass and sun-controls, and (iii) to compute the resulting internal temperatures and their diurnal variations. Radiation intensities have to be selected to accord with the manner in which buildings respond to solar heat gains. The radiation comes in during a short part of the day and warms the building, which cools down again at night. It takes some 3 - 10 days to reach a "steady cyclic" condition when diurnal temperature cycles are repeated and the highest internal temperatures are obtained, as illustrated in fig. 7.4
In the steady cyclic condition, the mean internal temperature is raised above the mean outside temperature by an amount determined by the daily-mean heat input, and there is a diurnal variation about this mean value. It is therefore appropriate to use radiation intensities on days of high radiation for design calculations, and to get a uniform basis for design calculations in different parts of the country we have used the mean intensity on the 5% of days of highest radiation. The value obtained and the calculation

of intensities on different building faces are discussed in paper 9. External temperatures assumed in design calculations are those occurring on the high radiation days; fig. 7.5 shows that daily-mean temperatures are higher than average on those days. Diurnal temperature swings (max - min) are also higher.

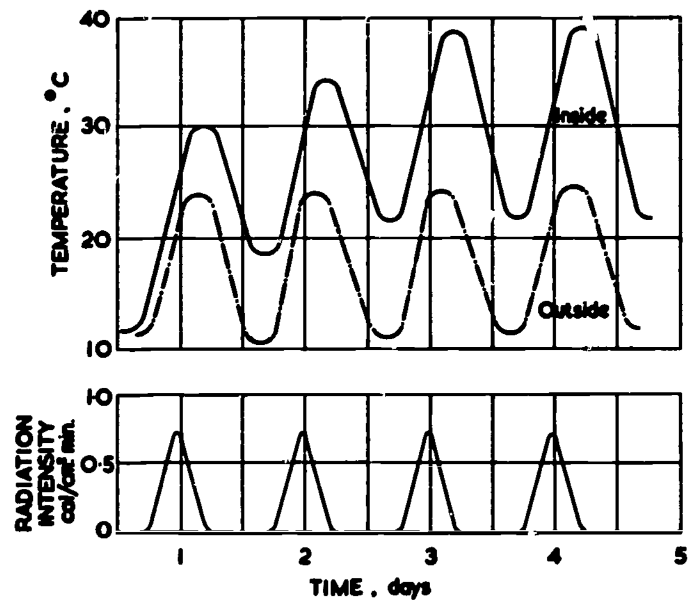


Fig. 7.4
Illustration of build-up of temperature during a sunny spell

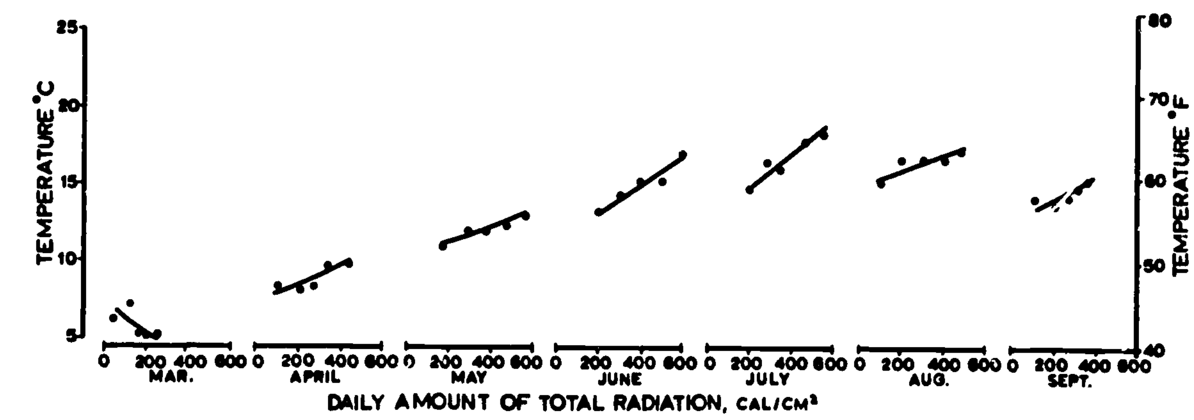


Fig. 7.5
Correlation between daily-mean temperatures and daily amounts of total radiation on horizontal - from measurements at Garston (1952-1962)

The transmission and absorption of radiation by glass and sun-controls are discussed in paper 13; the radiation transmittance and absorptance depend on the sun angle. The solar heat gain through a window is the sum of the transmitted radiation and that part of the absorbed radiation which is transmitted inwards - about 80 to 90% with internal blinds, 30% with single glass sheets, almost zero with external blinds. Radiation absorbed at the outside surface of walls and roofs also contributes to the heat gain.

This contribution is often negligible in comparison with the heat gain through the glass but when it is appreciable (e.g. with gains through the roofs of single-storey buildings) a simplified method of calculating the heat gain to the interior developed by Danter (4) can be used. Petherbridge (5) has prepared a system of sunpath diagrams and overlays for reading off solar gains at different times of day and times of year.
The temperatures resulting from the solar heat gains can be computed for steady cyclic conditions by methods developed by Danter, described elsewhere (Loudon and Danter (3)). The mean internal temperature can be calculated fairly straightforwardly by equating the mean heat gain from solar radiation, lighting, occupants and any other sources to the heat loss by conduction and ventilation; however there is a practical difficulty in assessing the ventilation rate in buildings where the occupants are free to open or close windows at will. It is less easy to calculate the diurnal variations in internal temperature, but Danter proposed a two-stage method for doing this. The first stage is to compute the cooling load required to hold the internal temperature constant, and the next to compute the temperature variations resulting from the fact that this heat is not removed but warms the building.

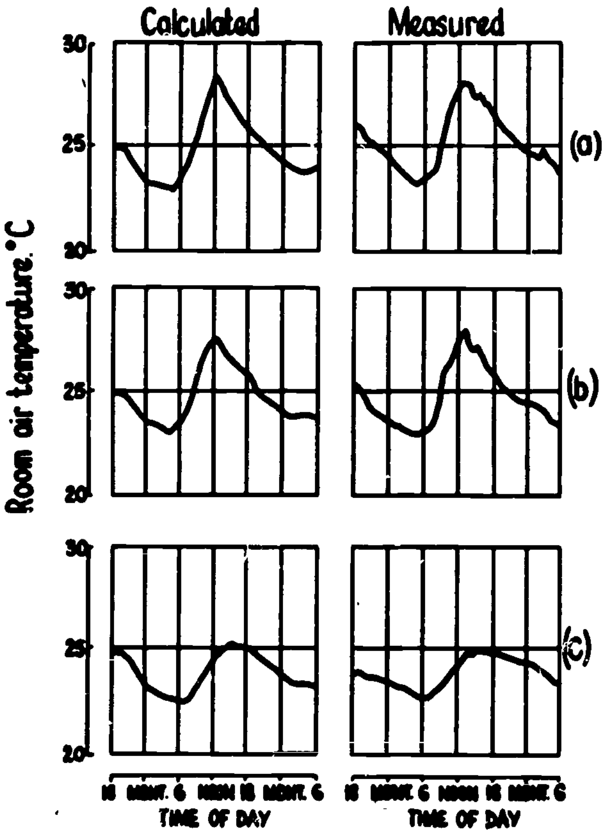


Fig. 7.6
Comparison of calculated and measured temperatures in offices
(a) Office with improtected glass
(b) Similar office, with white internal venetians, slats horizontal
(c) Similar office, with external woven plastic blind

The need for the first stage arises because the cooling load is not equal to the solar gain. For instance, transmitted radiation falling on a heavy floor warms the surface, and only part of the heat is re-emitted at the time and has to be re-emitted later. On the other hand, the part of the radiation absorbed by glass or sun-controls which is retransmitted inwards has to be removed in full. The different components of the solar heat gain thus require different consideration. Overall solar heat gain factors such as those in the IHVE Guide (6) or the ASHRAE Guide (7) give only an approximate guide to the reduction in cooling load.
The next stage in the calculations is to add all the components of the cooling load including that due to diurnal fluctuations in the outside air temperature and heat inputs from lighting, occupants and other sources, and where necessary that due to transmission inwards of radiation absorbed at the outside surface of walls or roofs. The total cooling load has a mean and a fluctuating component. The fluctuating component is calculated and divided by a quantity called the "room admittance", which can be fairly easily computed from the areas and thermal characteristics of the internal surfaces, plus a term for ventilation. This gives the diurnal fluctuations in internal temperature.
A point to note is that the "internal temperature" is not the same as the air temperature, but is a weighed mean between the mean radiant and air temperatures, 2/3 mean radiant and 1/3 air. This temperature was selected as convenient for heat loss calculations, but it is incidentally a better index of thermal comfort than the air temperature alone, or the mean radiant temperature alone.
We have made a number of field measurements in unventilated rooms warmed by solar heat gains, to provide a check against the calculations. Unfortunately steady cyclic conditions seldom occur in practice, but when they do, measurements agree fairly well with calculations, as illustrated by the three examples in fig.7.6, which were obtained during sunny weather.

Peak temperatures in design conditions could be calculated for any type of building by these methods. They have been worked out in detail for one example - the multistorey block illustrated in fig. 7.7 with single-glazed offices 11 ft. wide, 16 ft. deep, 10 ft. high (the average office size in the 1961 survey) and a central corridor. Calculations showed that the highest daily peak temperatures occur in August (when outside air temperatures are highest). At that time of year surfaces facing south of the east-west axis all receive similar amounts of radiation, only a little below their maximum values. Peak temperatures for August therefore apply reasonably well to all aspects south of the east-west axis.
Fig. 7.8 shows these peak temperatures plotted against window size (as a fraction of the area of the external wall) for "lightweight" and heavyweight" offices, and for ventilation rates of 2 and 10 air changes per hour. A heavy floor slab is assumed, and the terms "lightweight" and heavyweight" apply to the ceiling and partition walls.

These peak temperatures were compared with the 1961 survey data in table 7.1. The ventilation rate was taken as 2 air changes per hour in noisy areas, where it is not possible to open windows freely, and it was encouraging to find that peak temperatures computed on this basis were quite clearly related to overheating complaints in different categories of office. The ventilation rate to bring results for offices in quiet areas into line was found by a process of trial and error, assuming in turn 5, 10 and 15 air changes per hour; the best agreement with data for noisy offices was obtained assuming 10 air changes per hour. This indirect method of assessing the average ventilation rate had to be used because no data are available. Windows are opened or closed by the occupants at will, the extent of the opening being determined mainly by the fact that papers are blown about if the windows are opened too widely.
Fig. 7.9 shows the correlation between overheating complaints and computed peak temperatures for the condition of the survey. The survey finding that 80% of internal partitions were light and 20% heavy was used: the average size of office was correctly assumed; the ventilation rate was taken as 2 air changes per hour in noisy areas and 10 in quiet areas. The correlation indicates that the charts in fig. 7.8 might be used as a rough

guide to the maximum permissible area of unshaded glass in multistorey blocks of this type.
Overheating complaints could be reduced, though not eliminated, by designing to keep computed peak temperatures below 24° C or 75° F.

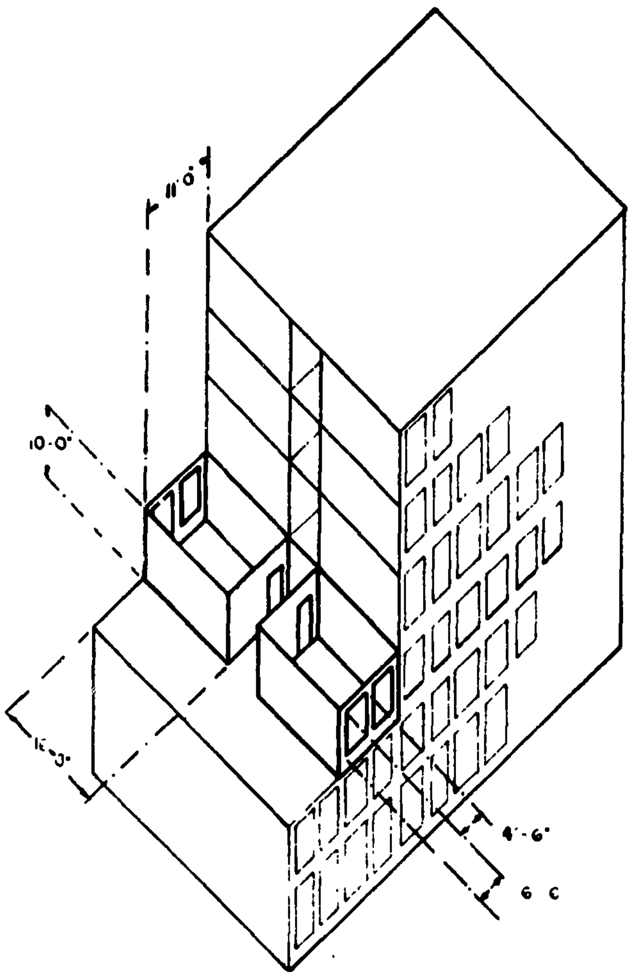


Fig. 7.7
Type of multistorey block assumed for design calculations

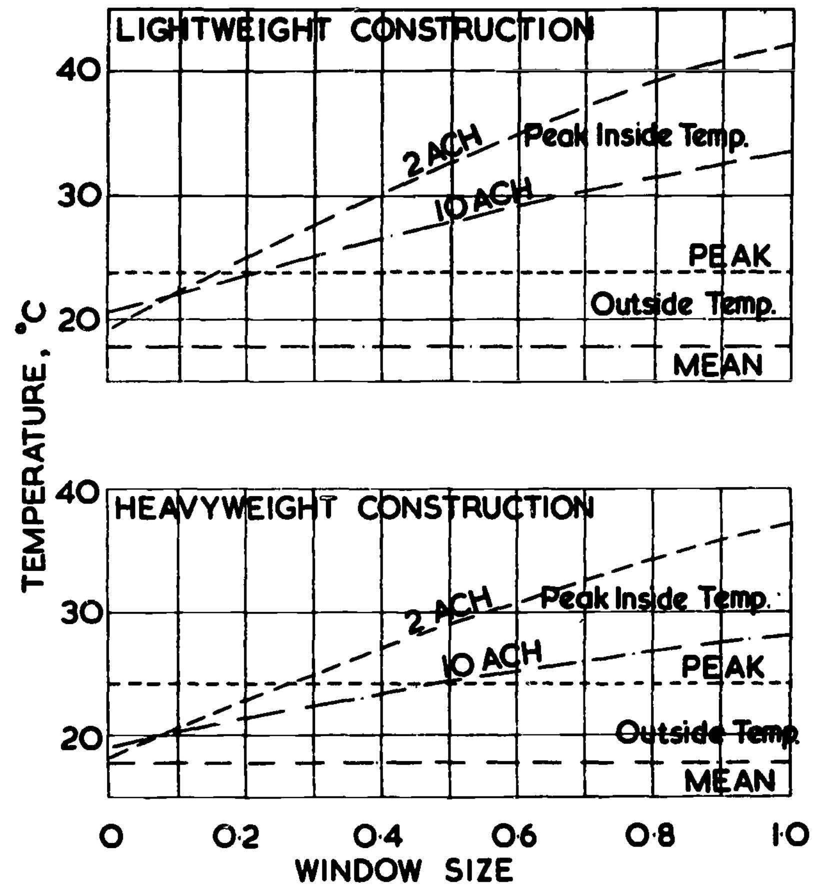
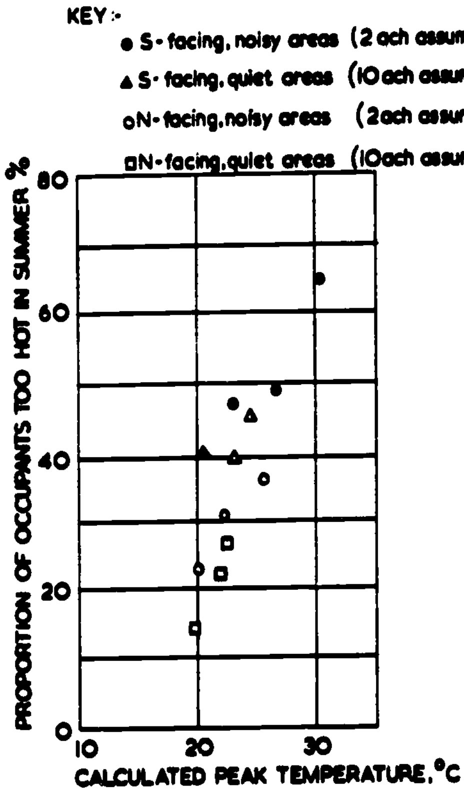


Fig. 7.8
Calculated peak temperatures in offices versus window size (window size is given as a fraction of the external wall area)

The results suggest, therefore, that buildings of heavy construction could have up to 50% of the external wall glazed, but that unless sun-controls were provided glass areas in buildings with lightweight internal walls and ceiling should be restricted to 20% of the wall area, if they face in a southerly direction and are not shaded. One could of course relax comfort standards and take, say, 27° C as the acceptable maximum temperature: this would bring the permissible glass area up to 30% of the wall area in noisy areas and 50% in quiet areas, for lightweight buildings. Alternatively one could use a sun-control. The effect of any sun-control of known characteristice can be assessed and though the calculations may be complex they can be simplified by average overall factors. One point that stands out clearly, however, is that external screens are much more effective than internal screens for reducing the internal temperature; this is because the heat absorbed by the screen is dissipated externally rather than in the room.

The curves of fig. 7.8 apply, of course, to one particular situation i.e., multistorey office blocks in the London area. As they seem to provide useful design guidamce it may be worth while to develop similar charts for different types of building and different climatic conditions.
If large windows are wanted to admit sunlight, provide a view, or for other reasons, the excess heat may be removed by air-conditioning equipment, but the expense of ductwork, cooling plant and running costs then have to

Fig. 7.9
Relationship between overheating complaints and calculated peak temperatures



be considered. The effective capital cost may be of the order of £8 per sq. ft. of excess unshaded glass, depending on the type of equipment used and the heating plant which it is assumed to replace. It may therefore be well to consider alternative methods of reducing temperatures such as external louvers or blinds, before using airconditioning in Britain to overcome problems of overheating by excessive solar heat gains.

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